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Patentanmeldung Nr. | Patent application No. | Demande de brevet n°

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Process for generating a circular periodic structure for a support for a magnetic storage means using interference lithography

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Description

Process for generating a circular periodic structure for a support for a magnetic storage means using interference lithography

Magnetic recording devices in the form of circular discs coated uniformly with thin films of magnetic materials are used in many information systems. The data is recorded in the form of magnetic bits in the thin film media. A magnetic bit means an area of the film that has been mainly magnetized in a direction by a "write head". The bit is read by a "read head" which is sensitive to the magnetization orientation of the bit. The disc rotates about an axis near its center during which the read and write operations are performed. Therefore the magnetic bits are positioned on circular tracks around the rotation axis.

The areal density of data storage on magnetic media has been increasing with a compound growth rate between 60-100% per year since early 90's. This has ensured lower cost for per bit of stored information and higher speed of access. Storage devices with areal density of 60 Gbits/in^2 (Hitachi/IBM microdrive) are expected to be in the market in the second half of 2003. The increase in aeral density means smaller "bit" areas on the disc surface. For the 100Gbit/in^2 generation, the area occupied by a bit will be ~80x80 nm^2 assuming a square shaped bit. The magnetic bits in thin film crystalline media may contain several tens to hundreds of magnetic grains. One must have a number of grains in each bit to maintain an acceptable signal to noise ratio. Therefore as the bit sizes decrease, the grains must get smaller as well. However this scaling cannot be continued indefinitely as one is confronted by the so called super-paramagnetic limit, which means that the grains are too small to retain their magnetization at room temperature for long enough periods of time.

A potential solution to this problem is to use patterned media where each bit is stored in a lithographically defined magnetic element. The elements behave as single magnetic domains so that they are stable at room temperature. Moreover they are isolated from each other so that their magnetization can be individually switched and read. An added advantage is that the transitions are expected to be sharper than continuous media. The elements should be placed in periodic arrays to be synchronized with the read/write signal.

A major obstacle to the realization of patterned magnetic media is the difficulty of mass producing the patterned substrates at an acceptable cost. The high aeral density above 100Gbit/in^2 requires bit sizes to be well below 100nm. Therefore the production technique has to pattern large areas, with very high resolution periodic structures at an acceptable speed and cost. Electron beam lithography is capable of producing such patterns but the throughput is too low. Laser interference lithography has long been viewed as a possible candidate as it can create periodic patterns over large areas. However up to now interference lithography has been shown to create only linear periodic structures such as arrays of lines or arrays of dots on square, rectangular or hexagonal grids. We have developed a new interference technique that is able to create periodic curved structures overcoming this limitation. Periodic structures such as concentric circular tracks and periodic arrays of dots on circular tracks are possible. The technique relies on diffraction gratings that can be patterned with known lithographic techniques including electron-beam lithography. The technique retains main advantages of interference lithography including high spatial resolution, large depth of focus, large pattern area, simplicity of the optical set up, coherence of the achieved pattern.

Description of the Process:

The process starts with the design of a transmission diffraction mask that would create the desired interference pattern when illuminated by spatially coherent light. This mask pattern is then written on a suitable substrate by means of known lithographic techniques including electron-beam lithography. The fabricated mask is illuminated with spatially coherent light and the resulting interference pattern is used to influence a substrate to create the patterned magnetic media.

The principle of the process is to obtain circular or curved interference patterns using light diffracted by diffraction gratings. This principle can be applied in different ways depending on many considerations such as the details of the mask or substrate processing and details of the material systems. Figure 1 shows a design for obtaining a pattern of periodic dots on periodic circular tracks. When illuminated with spatially coherent light this mask design yields an interference pattern with periodic intensity peaks along circular tracks as shown in Figure 2. In this case the desired pattern is obtained with the interference of three mutually coherent beams. This periodic light pattern can then be used to create patterned magnetic media with desired circular symmetry in a single exposure step.

The light beams diffracted by the three distinct gratings in Figure 1 coincide in region 3 at a certain distance from the diffraction mask to form the desired interference pattern. The gratings in regions 1 and 4 of Figure 1 are designed to define the circular tracks in the radial direction whereas the grating in region 2 is designed to define the partition of the circular track into individual intensity peaks along the circumferential direction. Even though the functions of these three gratings seem to be distinct, they are all required to obtain the desired interference pattern.

The design variations include exchanging the relative radial locations of the three gratings shown in figure 1. The spatial periods of the gratings, their diameters, the angle of the spiral-like grating with respect to the radial direction (between 0-90°) can all be changed according to the application requirements. The number of gratings can also be varied to obtain interference of two, three or four gratings.

An interesting possibility is to use a multiple exposure process to obtain the desired pattern. For example the substrate can be exposed first to obtain circular tracks with the diffraction mask in Figure 3(a) and a second exposure with the diffraction mask in Figure 3(b) can be used to create the circumferential partitioning of the circular tracks into individual bits.

Another multiple exposure scheme may include a first exposure combining a circular and spiral grating followed by a second exposure with a similar mask that has a spiral grating in the opposite direction as shown in Figure 4(a) and (b).

The described method obtains a circular pattern in an annular region, such as region 3 in Figure 1. In order to cover a larger radial range multiple exposures with different diffraction masks can be used. This helps maintain higher spatial resolution in outer regions of the patterned area as the number of bits along the circumference is constant in an annular region.

The diffraction gratings may be either absorption or phase shifting type. In the latter case the diffraction efficiency is higher, enabling more efficient use of the light from the source and consequently higher throughput.

The polarization of the incident light is important in the diffraction of light by the grating and the formation of the interference pattern. Linearly polarized light may cause

non-uniformities along the circumferential direction in the created patterns because of these reasons. Therefore light with circular polarization or linear polarization that varies over the exposure time may be used to avoid these directional effects.

The resolution of the obtained structures is limited by the light wavelength. In general pattern periods can go as far down as one half of the wavelength. Lasers with 193nm wavelength are currently used for lithography in the semiconductor industry. 157nm wavelength lasers are expected to be used for smaller features in several years time. Therefore interference lithography with the latter sources can in principle go down to approximately 80nm feature sizes. It is also possible to further decrease the effective wavelength, thus the achievable feature sizes by using the so called, immersion lithography, where the space between the diffraction mask and the sample is filled with a liquid. Therefore assuming an immersion liquid with refractive index 1.37 being used with 157nm laser source, then we can expect achievable pattern periods to approach 55nm. This corresponds to an aeral storage density of ~210Gbits/in^2. Shorter wavelengths are needed to go to even higher densities. Synchrotron radiation sources can provide spatially coherent radiation with wavelengths down to 10nm range. We have demonstrated x-ray interference lithography using a synchrotron source down to periods of 45nm using an interference set up with transmission gratings. Clearly the patterning ability with the x-ray interference goes down to 10nm range meaning aeral densities in the 10 Tbit/in^2 range.

This technique can be considered as a form of replication process even though the patterns on the master (diffraction mask) and the replica (circular magnetic pattern) are quite different. A noteworthy advantage in this replication is that the spatial frequency of the resultant magnetic patterns is higher than the grating mask. For example frequency multiplication by a factor between 1 and 2 is possible and often obtained. Therefore the spatial resolution requirement in the manufacturing of the diffraction masks is relaxed with respect to the desired magnetic pattern resolution.

The length to width aspect ratio of the structured magnetic elements can be varied with this technique. Elongated elements ensure that the elements have a certain long axis for easy magnetization. Such elements would have two opposite well defined magnetization states.

The transfer of the intensity pattern into the magnetic material can be done in various ways. Well known lithographic techniques using photoresist films can be used. In this patterning technique the photoresist film is exposed to the interference field. The pattern is created in the photoresist film after a development process where either the exposed or unexposed areas of the resist are dissolved away depending on the tone (positive or negative respectively) of the resist. The photoresist pattern is then transferred into a magnetic film using either a subtractive (dry or wet etching) or additive (lift-off or electroplating) process. Other possibilities include direct creation of the patterned magnetic media by the influence of the interference light on the material to be patterned. For example patterns of magnetic dots have been created by exposing the materials directly with laser beams [ref] and ion beams[ref]. The photoresist-less approach has several approaches. It avoids extra steps in the process. It avoids the damaging effects of the photoresist processing steps on the magnetic material. And it creates the magnetic patterns while maintaining the original smooth surface with no or minimal added topography. This is an important desired feature for patterned magnetic media since the magnetic read/write heads fly over the surface with an extremely small (several tens of nanometers) gap between the head and the spinning disc. Topographic features on the disc may disrupt the smooth flight or even collide with the head.

This interference lithography technique can be used in combination with nanoimprint lithography. In that case the circular interference lithography can be used to create stamps, which can later be used in the nanoimprint process for mass replication. The advantage here is to produce the stamps in a much higher throughput process than electron beam lithography. Unlike masks in photon based techniques, the lifetime of a nanoimprint stamp is limited due to the contact nature of the process requiring many stamps to be produced.

The interference process creates patterns with perfect periodicity which is important in the synchronization of the read/write signals.

Well defined circular tracks may be used to create a feedback signal for the head to follow the tracks. This can be accomplished either by using the signal from the read head directly or by including additional elements on the head which picks up signal from several tracks in the neighborhood. The control of the radial position of the read/write head on the disc surface is a critical problem in the current technology which is expected to get more challenging as aeral densities go up and track widths go down.

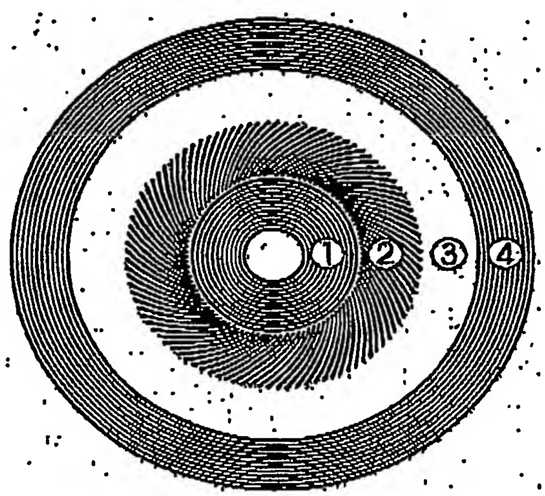


Fig. 1. *Schematic layout of a grating configuration for creating interference patterns with circular symmetry. Diffracted beams from regions 1, 2 and 4 coincide in region 3 to form a two dimensional intensity pattern with intensity peaks periodically positioned along circular tracks.*

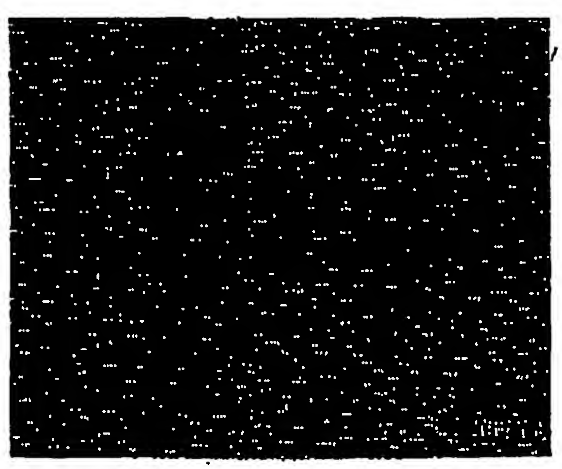
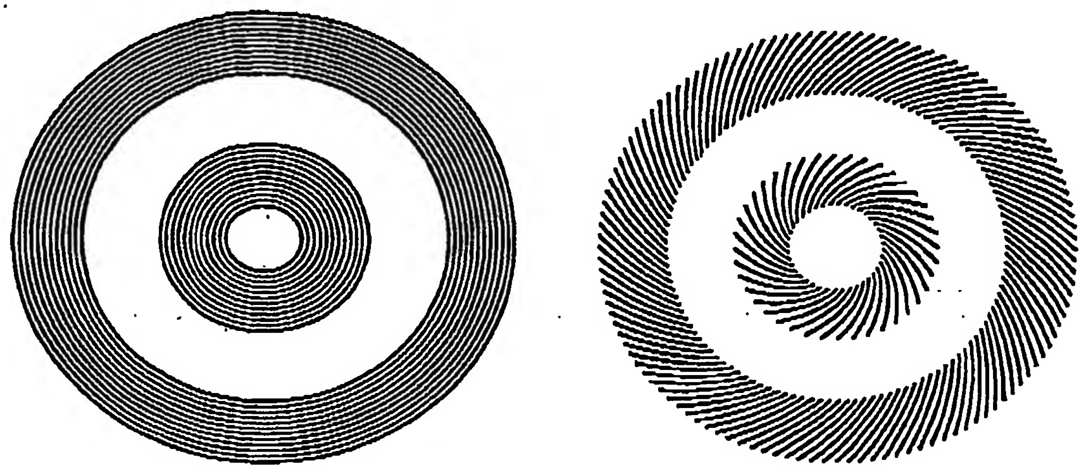
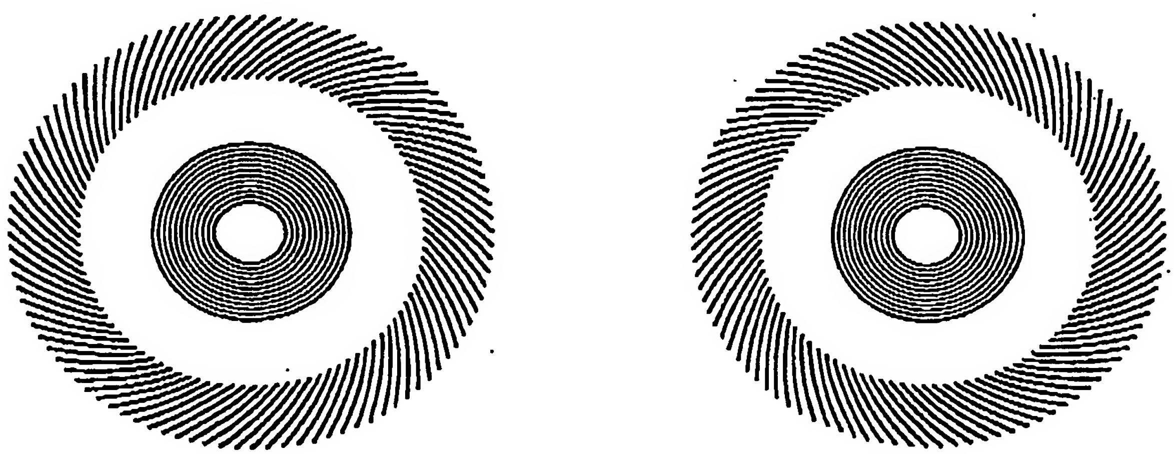


Fig. 2. *(a) Optical micrograph of an array of holes in photoresist obtained with the grating configuration shown in figure 1. The holes are positioned along circular tracks running parallel to the long axis of the oval shaped holes. Radius of curvature of the tracks is about 6mm so that the track curvature is not noticeable at magnifications large enough to resolve individual holes.*



(a) (b)

Fig. 3. *Schematic layout of diffraction gratings which can be used in a double exposure scheme. The first mask defines circular tracks in the annular region between the two gratings whereas the second mask defines periodic structures along the circular tracks.*



(a) (b)

Fig. 4. *Schematic layout of diffraction gratings which can be used in a double exposure scheme. The two masks form spiral shaped fringes individually which, when combined create a periodic pattern on circular tracks as in the other examples.*

H. Solak, Feb 7, 2003

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Patent Claims

1. A method for generating a periodic circular structure for a support for a magnetic storage device, comprising:
   a) generating a number of transmission diffraction masks each having a different periodic circular and/or radial interference mask pattern;
   b) positioning at least two of said diffraction masks in a certain distance of a basic support material;
   c) applying light and/or electron beams through each of the at least two diffraction masks for exposuring the basic support material to said light and/or electron beam;
   d) interfering the different light and/or electron beams in order to generate conincident light and/or electron beams pattern on the surface of the basic support material to form a periodic circular structure.